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Issues of Effective Integration of Solar Power Plant with Local Power Grid

Kasimakhunova Anarkhan Mamasadikovna
Ph.D., Professor, Fergana State University, Uzbekistan

Mamarasulov Kudratbek Shukhratbek Ogly
Doctoral student, Fergana State University, Uzbekistan

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Abstract: The article studies the possibility of improving the most efficient integration of solar power plants (SPP) with the electric grid by analyzing foreign scientific literature. The reasons for the inefficient integration of SPP and the power system are identified based on the results of scientific theoretical and experimental works by leading experts from developed countries. The issues of variability of weather conditions, the influence of external and internal factors on the operation of the network, the use of the most advanced technologies for managing the network, the method of accumulating the generated energy by batteries and their impact on the distortion of the energy parameters of the network are considered. The issues of introducing the technology of modern converters, anti-islanding, protection, forecasting the "sun-grid" system and smart grid are described. The methods of various scientists used in the integration of solar photovoltaic plants to electric grids and their results are discussed. Attention is paid to the development of control algorithms, the creation of simulation schemes of models. The main directions of methods for efficient connection of SPP to electric grids are indicated. Possible cases of failure of power plants, power lines and the safety of the entire system are taken into account. The technical and economic aspects of the problem of the issue under consideration in the construction of integrated systems in hard-to-reach areas of the planet are considered. It is recommended, as an important step, to optimize the implementation of Internet of Things (IoT) technology, smart monitoring of the generation of electrical power received from solar power plants, accumulation and consumption of energy by consumers.

Keywords: Solar power plant, electric grid, integration, efficiency, control, protection, security, continuity, advanced technology, algorithm.

Introduction: It is clear that over the last twenty years, from the point of view of climate change and energy security, significant work has been done in the field of integration of alternative sources of electrical energy with the electricity supply system. The result of this is an increased interest not only by the public authorities of energy facilities, but also by the population of countries. Among non-conventional sources of electric energy, the generation of the latter and reducing the consumption of gas fuel in greenhouses, the most realized by the use of solar energy. Photovoltaic systems (PV) in this sense are efficient and quite durable. In addition, they already require relatively low costs compared to some alternative energy sources and minimal operating conditions.

In recent years, the integration of solar power plants into the power grids of the energy system has started to develop. Such a possibility allows to maximize the use of converted energy by consumers of different types such as technological installations of industry and population. According to the opinion and conclusions of international observers, as a result of the development of industry and the increase in the amount of energy exchange, the amount of CO2 gas emitted into the atmosphere is increasing[1÷3]. This can be clearly seen in Figure 1.

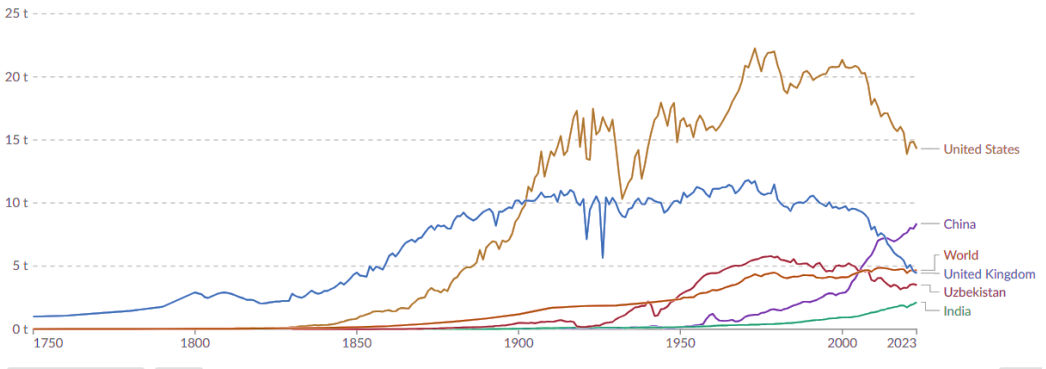

Figure 1. Amount of CO2 gas spreading into the atmosphere [1].

There are some recommendations to address this problem. The first of them is [2], in order to solve this problem, the creation within regional, national, or even global levels of the energy system, linked by larger interconnected systems, for the sharing of resources. In this direction, extensive work has been done by the Global Energy Interconnection Development and Cooperation Organization (GEIDCO). The second of them is aimed at the creation of self-managed sustainable networks for large energy systems, development of regional solutions and smart energy systems.

Due to the emerging conditions of local power producers, many changes in technology and business are taking place. In particular, this is the case for generators for various purposes and electricity storage systems. From a technological point of view, the highly variable generation of electricity from renewable energy sources, their operation and the implementation of protection pose particularly big problems. From a business point of view, electricity generated by local energy producers belongs to small electricity consumers. This diversity leads to the formation of the local market and its development.

The integration of solar power plants covers modern converter technology, anti-islanding technology, protection, solar-grid forecasting and smart grid. It is well known that the electricity generated by solar cells is directly supplied to the consumer. Excess energy is recorded by meters. In SES inverters integrated with power systems, “anti-islanding” protection is required at the moment of blackout in order to stop the power flow. Modern hybrid inverters and “on-grid” inverters are able to maintain grid stability by controlling the voltage. Their advanced PV capabilities are tested in research centers using simulation devices. The simulation period is conducted under near realistic conditions and their power reliability and quality impact are studied.

In case of power increase from the network demand, when it is transferred from the SES to the power systems, due to the negative effect on the network frequency and voltage, the stability of the power network is disturbed. Therefore, considering the continuous increase in the number of solar panels, the reliable management of the integrated solar power system and its efficient utilization with the power grid require new management strategies.

The ability to generate electricity from photovoltaic systems is considered to be the most basic property. These properties, depending on a variety of indicators, vary from application to application and technology. The efficiency is only increased by precise calculation at the time of installation. However, despite the rather high accuracy of accounting for all the influencing factors on the operational properties of SES, there are a number of problems that arise during their operation and repair. Especially such problems are often encountered in the operation of SES in hard-to-reach areas of the country. In this regard, adaptive integration approaches should be developed to eliminate similar problems. In this regard, Internet of Things (IoT) technology [3] is the most promising in continuous monitoring of SES systems. The present technology helps in obtaining accurate and detailed information on objects and provides new opportunities for various developments.

Hence, it can be concluded that integration of solar PV plants to regional power grids is of particular importance in ensuring sustainability, efficient utilization of environmentally beneficial sources and providing diversification of power generation. In addition, there are opportunities to effectively utilize alternative energy sources, reduce power loss and energy independence of the region. It should be noted that when integrating SES with local power grids, technical and managerial problems arise in addition to the above-mentioned. For example, the natural variability of solar energy, which affects the stable operation of the grid, contributes to the need to optimize energy distribution and balancing systems. For this reason, the integration of SES into local power grids requires modern control methods, smart grids

(Smart-Grid) and the introduction of energy storage technology. In general, the integration of solar photovoltaic plants to local power grids plays an important role in ensuring the sustainability of electricity, improving efficiency, reducing carbon waste and developing energy generation with innovative technologies.

METHODS

With the increasing demand of the population for electricity, the issues of efficient integration of solar photovoltaic plants to the power grid are becoming more and more relevant. This is due to the reduction in the cost of generating electricity in the traditional way, reducing the need for combustible materials, fossil fuels. However, the problems associated with the connection of solar power plants to the power grid, as well as their impact on efficiency, require the development of increasingly advanced and optimal methods of their integration. In this regard, in recent years, the amount of research devoted to the integration of solar power plants with power grids has increased. Our analysis of more than 30 scientific papers in this direction shows that there are certain methods of integration of these two sources of electricity. The used terms such as “integration of solar photovoltaics to the grids”, “optimization of grid connected solar photovoltaics”, “new methodology of connecting solar photovoltaics to the grids”, “state-of-the art analysis of integrating solar photovoltaics” and their word combinations were used in the search of IEEE xplore, ScienceDirect, Springer, Scopus, Research Gate va Google scholar databases in order to find relevant scientific articles.

The work of the authors [4] presents considerations for increasing the efficiency of solar energy, reducing the need for fossil fuel resources and consists of recommendations of strategies for the formation of integrated and independent energy systems. It also proposes the development of energy conservation and storage technology due to the variability of solar radiation and the use of advanced grid technologies. In addition to the proposals, the article considers the use of additional technological advances, allowing good integration and the problems associated with this method. Among the latter are technical issues directly related to the expansion of the network and investment costs, difficulties in management and economic issues reflecting the impact of the socio-environment.

Researchers led by Rong Hieh recommended the use of Modular Multilevel Converter (MMC) technology in photovoltaic power generation networks. Their work proposed to improve the technology with matching the temperature and degree of illumination of the surface of the SES. It has developed, in addition to traditional problem solving algorithms, the most sophisticated algorithms for plant control [5]. In this work, the efficiency of power generation has been achieved, using multi modular converter technology. By arranging the lighting intensity and temperature with the help of algorithm, a sophisticated control algorithm is implemented. By comparing the results, the superiority of the complex algorithm over the traditional existing algorithm is revealed (Fig.2). It was found that according to the results of simulation performed during the study period, when increasing the light intensity from 750 to 1000 W/m2, the value of DC voltage increases for a short time, but then, quickly decreases and approaches the initial steady level. From this it can be seen that even if the light intensity varies in duration, when the DC bus is connected to the MMC network, it is possible to maintain the voltage value continuously. Such a provision ensures the steady state operation of the whole system. Figure 3 shows the simulation diagram of the recommended model.

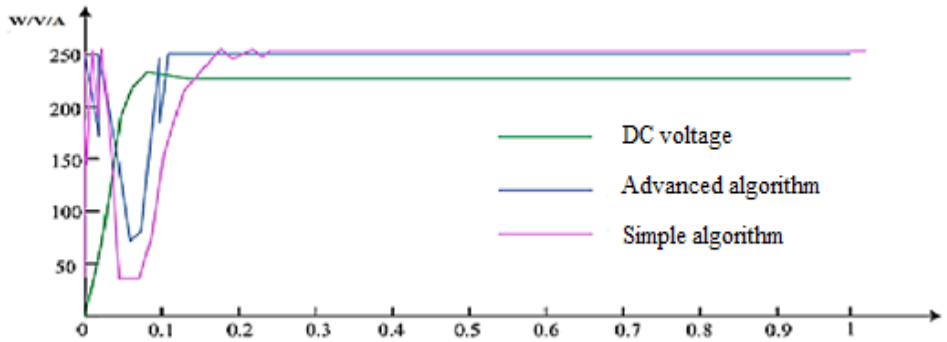

Figure 2. Simulation comparison of the algorithm MPPT

The traditional MRRT (Maximum Power Point Tracking) faces difficulties in ensuring power quality, due to the variability of the illumination level of the solar module front surface and hence its temperature.

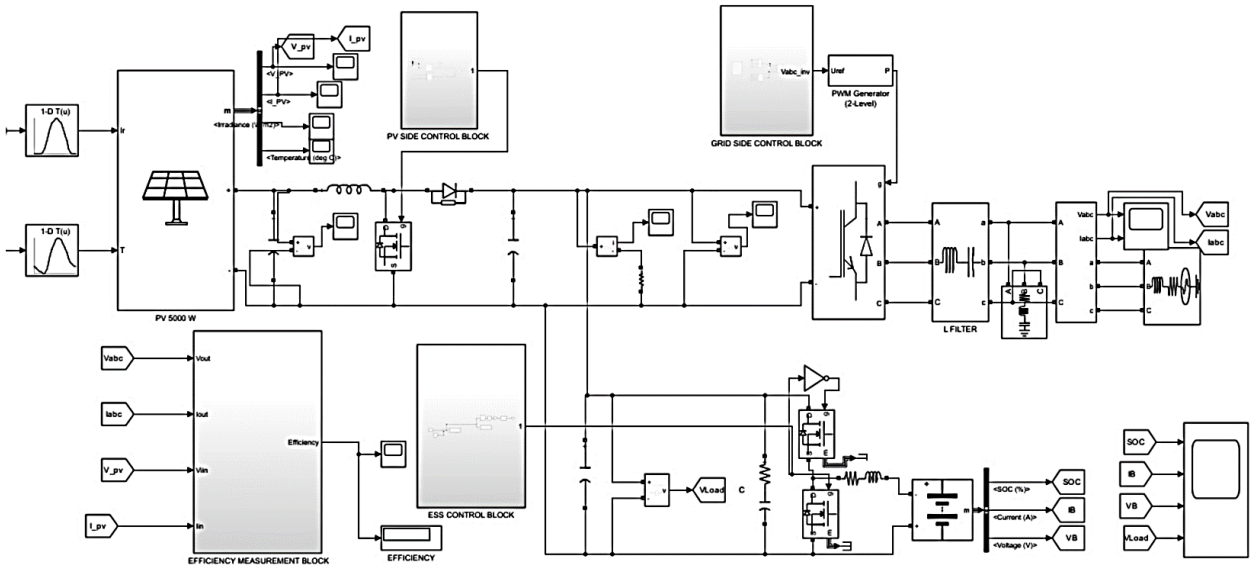

Fig.3. Simulation diagram of the recommended model [5].

L.Nandhal et al. in their research work [6] proposed an advanced method combining Incremental Conductance (InC) wa Function-Fitting Neural Network (FFNN). This hybrid method increases the conversion efficiency of PV system, improves the tracking accuracy, stability of the system. In addition, suggests the non-optimality of inverter control methods, while ensuring the stability of the network and reducing the total harmonic distortion. They solved this problem by control using a voltage matched power supply. This made it possible to integrate voltage, current and load distribution and maintain grid stability with a voltage of 300 V and a current of 12 A, even under varying PV conditions. Thus, the methodology recommended from the study results improved the power quality and system efficiency to 97.8% while reducing the common harmonic distortion to 0.02% (Figures #4(1.5) and 5(1.6)).

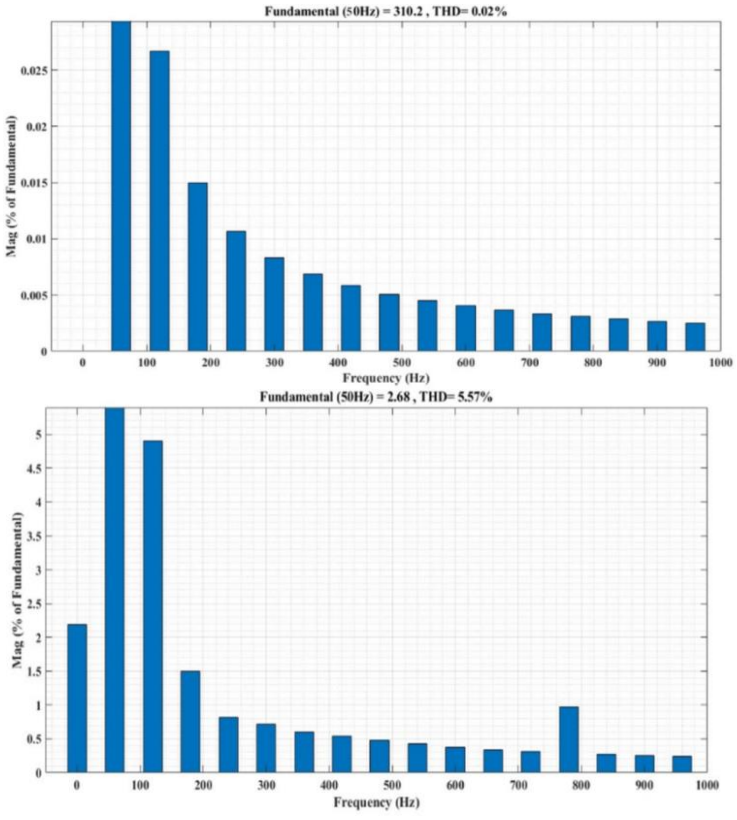

Fig.4. (a) Harmonic damage degree using IncCond MPPT, (b) Harmonic damage degree using Intelligent IncCond MPPT [6].

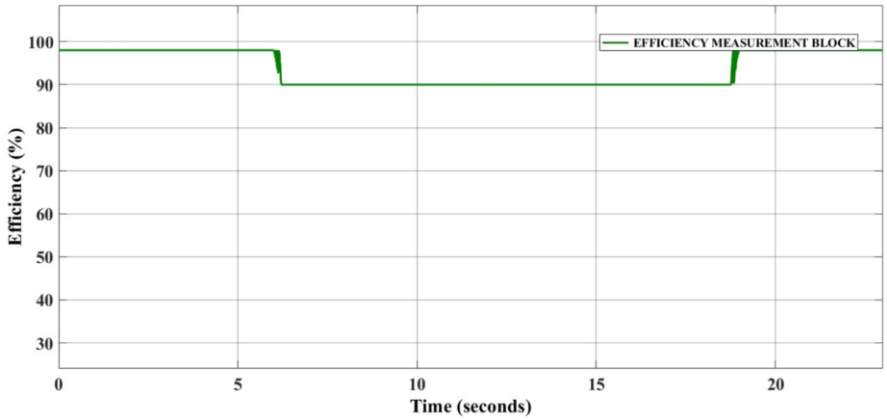

Figure 5. Effectiveness of the recommended management system [6].

In the research led by Mottahir Alam [7]in order to identify the faults on PV systems and categorize them into classes, “Deep Belief with Buffalo Optimization (DB-BO)” algorithm was developed. In addition, by them to analyze the power loss, principal component analysis and linear discriminant methods were used to reduce the deviation. As a result of the study by using DB-BO algorithm, they were able to reduce the power loss value to 3.4mW. In the research by R.Singh et al. the efficiency and reliability of grid connected predetermined PV system was studied. For this purpose, they considered the degree of electrical power generation of the PV system and the influence of factors on it, using Machine learning algorithms, in particular the Support Vector Regression (SVR) algorithm [8]. The recommended algorithm in the article [8] SVR algorithm serves for storing information on the generation of electric power by solar plants and predicting the state of weather conditions, as well as in-depth analysis of the dynamic conditions of the network. The present recommended model has relatively low error values and the RMS error value for the SVR is 2.002%. At the same time, the average absolute value of solar converters decreased to 0.547%.

To solve the problems at hand, M. Rafiei and his team used mathematical modeling to increase the efficiency of a grid-connected solar power plant [9]. Their experiments also took into account many external influencing factors such as solar radiation, humidity, dust, temperature, shading. In order to realize the objective, having considered various nonlinear models, the matching method on nonlinear parameters was applied to optimally determine the unknown parameters. According to the results of the study, as well as in some previous works it was found that the efficiency of SES mainly depends on temperature and dust, the influence of humidity is insignificant. Indian scientists M. Amir and his team [10] worked in the same direction in parallel. Their work recommends a control method coordinated on the basis of Intellegent Energy Monitoring System (IEMS) for solar powered energy charging station. The present recommended smart energy management charging station optimizes grid power utilization by analyzing real-time metrological information and load conditions. As a result of applying the IEMS coordinated control method, the energy exchange between the distribution grid and the car charging station was ensured, and the maximum power demand was reduced by half.

In order to solve this problem, a two-stage optimization of alternative energy systems was proposed by Chinese scientists under the leadership of Di Lu [11]. This method allows for a more accurate prediction of the capacity of the SES, covering the information on the daily generation of the SES and the stages of planning the daily generation of electricity. In contrast to the Chinese scientists, A. Siosia and his team, in their scientific research, developed the same two-stage optimization based on seasonal analysis of power generation. Comparison of the study results shows that the difference between the values determined by simulation and the measured annual energy is less than 2%[12]. For a similar use of neural network, M.Abubakar [13] worked [13]. He proposed to augment with long-short term memory (LSTM) and gated recurrent unit-(GRU) models. The result showed superiority over other models, achieving at 97% accuracy of the model considering long term memory.

In order to achieve the stability of the network integrated with SES with the local electric grid, J. Zhao proposed a way to take into account the power planning of SES with regard to the needs of consumers for heating, ventilation and creation of climatic conditions in the premises [13]. This was accomplished by developing a model that allows predicting solar radiation based on an optimized neural network algorithm. By comparing the results of this developed model with the results of other existing models, it was found that the variability of the total network load and energy saving rates during summer period decreased respectively: 47,5 % *и* 10,89 %.

The study and analysis of the above-mentioned works shows that so far there have been proposed many ways of effective connection of SES to the electric network, supplying electricity to consumers in the traditional way. Their main directions are as follows:

-Ensuring grid stability: implementation of advanced control algorithms in order to achieve sustainable operation of the grid by studying the impact of PV system connection on the grid;

-Optimization of grid operation: when integrating the SES with the grid, finding the optimal location of the SES, power flow control and implementation of scientific developments related to power flow control and load distribution;

-Power quality improvement: development of advanced technologies for balancing the frequency and voltage variations arising from the interconnection of PV systems with the grid, including active and reactive power management strategies;

-Energy storage systems: makes a proposal to improve system stability when integrating PV systems with batteries.

Thus, a preliminary conclusion can be made about the importance of the role of the use of smart-grid technologies (smart-grid) and energy storage, innovative control technologies. And, in this regard, analyzing the results of the reviewed works, is the basis for the creation of methods of comparison and form of management strategies.

Analyzing the emerging technical and economic challenges of integrating solar PV plants with the grid. One of the main areas of research in the integration of solar PV power plants is the implementation of “Fault Ride-Through (FRT)” and “Low Voltage Ride-Through (LVRT)” control strategies. The validity criteria for this are, with their advantages and disadvantages, the consistency of the available strategies to the network parameters, their complexity, cost-effectiveness and overall performance.

Like other systems, the SES also has a propensity to malfunction. This has a significant impact on the reliability, efficiency and safety of the system. Therefore, traditional protection standards may not be sufficient to protect the SES. For example, since SES faults are due to the low current value in conventional protection systems, the non-linearity of PV parameters and properties, low illumination, the transition from night mode to day mode and vice versa, the presence of a maximum power controller and blocking diodes it is not always possible to accurately determine the faults of the PV system. In addition, due to the difficulty of predicting faults in advance, despite the presence of protective equipment, the entire PV system can catch fire [15].

This area is one of the least studied problems worldwide. Compared to the work on solar module reconfiguration, very little attention has been paid to this area. There is still insufficient scientific work to analyze the performance of SES in terms of protection schemes and their accuracy, complexity of integration, cost, and efficiency. Therefore, it is still necessary to carry out a lot of scientific and research work on the protection of not only SES, but also the entire system in a comprehensive manner.

There is one more important factor. Usually solar power plants of large capacity are installed in remote areas of the planet. They are not rarely used for power supply in sea and ocean conditions [16, 17]. In this regard, the construction of such stations requires large capital expenditures. This leads to a difficult situation for investors. In addition, such an arrangement of SES plants, and its possible integration with the local grid, requires remote monitoring and control solutions to ensure efficient and reliable operation. If roofs of buildings are used, due to the dense arrangement of solar modules, when it is necessary to have a large capacity, there are difficult conditions for maintenance, inspection and repair of them. Such problems can create unnecessary limitations and faults in power generation. We should not forget the presence of important problems related to connectivity and security, environmental, socio-economic and energy market. All these require conditioned extended studies before researchers.

Of course, based on this, it can be concluded that there are several problems related to technical and economic issues in the integration of SES to the grid. These in turn are mainly related to grid stability, transmission and distribution losses and investment costs. Particularly noteworthy is the variability of weather conditions, in which electricity generation is highly unstable and requires the provision of storage facilities. It is impossible to supply consumers with continuous power without accumulation for power reserves.

CONCLUSION

According to the results of the study and analysis of foreign research work, we can conclude that the inefficient management of the system, integration of it, undoubtedly requires even more scrupulous research work and so far requires large economic costs. Hence there is a decrease in overall efficiency. Therefore, it is recommended, as an important step, to optimize the implementation of Internet of Things technologies, intelligent monitoring of the generation of electricity from solar power plants, the accumulation and

consumption of energy by consumers. With the help of IoT device, it collects real-time information and balances the energy flow control, network loads, and reduces transmission losses. Therefore, a deep study of the application of IoT technology in integration with solar power plant network with battery energy storage devices is required. In the future, advanced control approaches developed through research and innovative solutions serve for efficient operation from a technical and economic point of view.

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